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TITLE: The Burn Medical Assistant: Developing Machine Learning Algorithms to Aid in the Estimation of Burn Wound Size

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14. ABSTRACT
We will test the hypothesis that a computer machine learning algorithm can analyze and classify burn injures using multispectral imaging within 5% of an expert clinician through a series of steps. First, we will develop a model to map images of burn wounds captured from a portable multispectral camera to a standard Lund-Browder burn wound diagram. We will then have burn wound experts estimate the burn wound size using an enhanced burn wound diagram. The mappings made by burn wound experts will then be compared to automated measurements. Finally, through the use of machine learning (ML), we will build models from these multispectral images and expert burn wound mapping to create a predictive model of burn wound size and depth that will approximate an expert's opinion to within 5%.

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Cognitive Engineering, Human Factors, Health Information Technology

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1. Introduction and Project Overview

A major challenge in pre-hospital field settings is the accurate identification of wounds, in particular burn wounds, such that the clinician (e.g. medic) can provide optimal care. Specifically, the identification of the burn size, location, and depth are critical to initiating appropriate therapies in the field. Currently, Joint Trauma System (JTS) guidelines recommend using the "Rule of Nines" to estimate the burn wound size or to use a Lund-Browser chart if available. Recent data comparing pre-burn center and burn center wound size estimation demonstrated an average of 7±7% (range 0-32%) difference between novice and expert estimates. These differences included both over- (novices estimated the burn size to be larger than the expert) and under-estimating (novices estimated the burn size to be smaller than expert) the extent of injury. Many (43%) were over estimations. Rarely was the novice estimate of burn size the same as the expert estimation, whereas experts compared to experts usually estimate burn size within 5% of each other. These discrepancies introduce large amounts of error into the standard equations used to predict resuscitation fluid volumes during the first 24 hours post-burn injury. Civilian data is similar: novice clinicians routinely miscalculate the size of burn wounds, with differences between novice providers' assessments and those of experts being reported to be as large as 100%. This variance results in significant differences in the amount of fluid used to resuscitate patients and increases the potential for resuscitation morbidity.

In response to these challenges, the USAISR developed and obtained FDA 510(k) clearance of the Burn Navigator™, a computer decision support system to guide fluid resuscitation in the field environment. The device is designed to assist novice burn care providers with resuscitation during the first 24-48 hours of resuscitating patients with large burn wounds. Unfortunately, inaccurate burn wound size estimation, when entered into this computer decision support software (CDSS), can significantly change the CDSS algorithm's recommendations and thus the total fluid administered to a patient. The objective of this project is to develop a decision support software application that will aid novice burn care providers with the assessment of thermal injuries. The Specific Aims of this proposal are as follows:

1. Create a multispectral image database of burn wounds that can be used for machine learning and a de-identified database of Enhanced Burn Wound Diagrams;
2. Create and teach a Machine Learning (ML) algorithm to estimate burn severity and size from imaging data to within 5% an expert's opinion;
3. Produce a reference design for a portable imaging and burn wound prediction design.

The objectives of this project include:

<u>Objective 1</u>: Place images of human subjects onto a standard anatomic diagram of the human body and create a multi-spectral image database of burn wounds for ML.

Task 1.1: Provide a multispectral camera or other advanced imaging platform for image data collection at the USAISR
- ARA will deliver camera to USAISR
- USAISR submits and obtains IRB and IACUC approvals.
- USAISR images healthy volunteers, burns on a porcine burn model, and patients admitted to the burn center.

Task 1.2: Create de-identified database of enhanced burn wound diagrams (multi-spectral burn wound images superimposed on standard, digital, anatomical, burn wound mapping diagram of the human body).
- Software engineers at the USAISR and OSU create enhanced burn wound diagrams.
- USAISR sends de-identified imaging data to ARA for preprocessing.

Task 1.3: Produce multi-spectral burn wound images and enhanced burn wound diagrams for automated, multi-spectral feature extraction and image segmentation.
- ARA will pre-process multi-spectral burn wound images to validate that registration and transformation into the standard, digital, anatomical, burn wound diagram of the human body, does not introduce disruptive artifacts.

<u>Objective 2</u>: Compare results of the burn wound mapping and total body surface area (%TBSA) estimates derived from clinical experts using current best practices, existing technologies and innovative multi-spectral machine learning.

Task 2.1: Expert annotation of enhanced burn wound diagrams within the de-identified data set.
- USAISR will transfer de-identified enhanced data set (minimum of 10) to ARA and OSU. The data set will include de identified data generated by using a standard, digital, anatomical, burn wound mapping

diagram of the human body, depth maps from the camera and multiple spectral images from the camera.
- ▪ OSU uses enhanced burn wound diagrams and their existing software to trace wounds and estimate of % TBSA.

Task 2.2: Experts in burn wound care at USAISR estimate wound size and burn depth; review OSU's enhanced burn wound diagrams to confirm or correct these estimates as needed
- ▪ Create a machine learning model. (Months 5-19)
- ▪ ARA uses training data set to create ML algorithms to automatically estimate burn wound depth and %TBSA.
- ▪ ARA uses the evaluation cohort to demonstrate the ML algorithm reaching within 5% of expert's judgment

Objective 3: Teach machine learning software to model raw images of burn wounds.

Task 3.1: Use the training data set from the multispectral burn wound image data and the enhanced burn wound mapping with clinical expert annotations to create ML algorithms to automatically estimate burn wound depth and per cent TBSA burned.

Task 3.2: Use the evaluation data set to demonstrate the ML algorithm will determine meaningful patterns identified in the spectral data to predict the type, size, and location of burn wounds within 5% of a clinical expert's judgment.

Objective 4: Produce a reference design

Task 4.1: ARA will produce a reference design for a mobile (hand carried or helmet mountable) camera-computer platform that incorporates high definition imagers and the machine learning modeling software usable in a PFC setting.

2. **Technical Progress**

    a. **Team Management**

The ARA team assumed project responsibilities following the award of the contract on September 1, 2017. Due to negotiation issues and a mismatch in technology, RVS was dropped from the team before the subcontract to them was awarded. ARA acquired and will be delivering an alternate camera system directly to USAISR instead. OSU is not yet under subcontract, but will be by the time data acquisition begins.

    b. **Protocols**

There are three protocols for this project, including the Laboratory Protocol to govern initial data collection using manikins and healthy volunteers, an Animal Use Protocol to govern collection of porcine burn wound images for initial ML development, and a Human Use Protocol to govern collection of human burn wound images for both training and validation of the BURNMAN ML software.
- *Laboratory Protocol – We have written and submitted a laboratory protocol for initial software development using digital images of manikins to the USAISR regulatory department. The USAISR SOP's are currently still under revision, and the status of our protocol is pending these revisions which may direct a different pathway for approval for this type of work (i.e. preparatory research and development). In the meanwhile, we continued our efforts to take images using the Microsoft Kinect system for initial software development for this device.*
- *Human IRB protocol – Dr. Jeremy Pamplin has written the first draft of a human protocol. We have made modifications to the first draft version upon our discovery that the MS Kinect device may not be feasible for this project. We have been unable to finalize the protocol until we know what type of thermal imaging camera we will be using for the study. This information is still pending. ARA just came under contract in September, 2017. It has recently been determined that a sub contract with Raytheon will not occur, this in conjunction with ARA, we are in the process of market research with currently available Commercial off the Shelf (COTS) cameras. Once we receive the camera and learn about its functionality and limitations, we will revise the human protocol accordingly; send it out for scientific review and for pre-review through the USAISR regulatory department.*
- *Animal protocol – We started collaborations with, Dr. Randolph Stone, PhD, who routinely conducts several IACUC approved porcine burn-wound research studies. Dr. Stone has experience developing swine burn wound models and taking pictures using different types of thermal imaging and multi-spectral*

imaging cameras. Taking wound images is a non-interventional study, so protocol amendments did not need to be submitted per our IACUC regulations. Ms. Veazey has been added as an Associate Investigator on Dr. Stone's current protocols. Dr. Stone has agreed to allow Mr. Fenrich to take photos and did not need to be added to the protocols. Ms. Veazey and Mr. Fenrich have completed the required animal training. Ms. Veazey and Mr Fenrich has fulfilled the regulatory and occupational health requirements to conduct research in our vivarium. Ms. Serio-Melvin still has a few classes to complete. Our studies have begun in September.

c. Equipment Acquisition

We have acquired and evaluated multiple cameras for potential use in this project. These include the Kinect, RealSense, FLIR One, Hero 5 GoPro, and Euclid cameras. A short review of each is provided below. With the dropping of RVS and the fact that the original Pixnet camera is not available for this project, we have elected to use the MSI Camera for multispectral burn image data acquisition. Various cameras were evaluated to ensure we identified the deal methodology of detecting a human body while removing the background.

- Kinect: The IR capabilities of the Kinect system are only used for depth detection. The Kinect system has a clipping plane of 1 meter to 8 meters; therefore any object closer than 1 meter or further from 8 meters will be clipped from view. The IR image resolution is also smaller (at 512x424 pixels) while the visual image resolution is larger (at 1920x1080 pixels). All body mapping work performed to date was completed using the Kinect camera and is described in the sections below.

- Intel® RealSense™ Camera ZR300-Series does human body detection and uses an infrared camera similar to the Kinect system. The IR camera of the RealSense Camera is used for depth detection as is the IR camera of the Kinect. This camera also utilizes the OpenCV library to assist in the body detection algorithm that is support with the SDK that comes with the camera.

- FLIR One Pro camera connects to an Android smart phone/device and can take thermal imagining pictures while connected to the smart phone. After evaluation, we determined that the FLIR One did not have sufficient resolution to work for our application.

- Intel Euclid Camera includes the RealSense™ depth camera technology, a motion camera, and an Intel® Atom™ x7-Z8700 Quad core CPU to produce a compact and sleek all-in-one computer and depth camera. This systme includes the same hardware as the RealSense on its own, but with an integrated CPU.

- Hero 5 GoPro camera is a small camera and can be controlled by an App that you download. You can connect to it via Bluetooth or Wifi but the distance in which you can control the camera is not very long. The camera did not appear to provide any additional use to the requirement for pictures usable in body mapping.

- SpectroCam VIS-NIR 5MPixel camera system. We selected the Spectrocam based on a thorough market survey of current COTS technology and after review of the technology offered by RVS. This system offers the necessary resolution, flexibility, and spectral bands to support the research objectives.

A mounting system has been acquired for the cameras which attaches to a standard Computer on Wheels (COW) cart in the Burn Center. When acquiring animal images, the camera system will be mounted on a similar cart used in the vivarium.

d. Image Capture Method Development

Here we describe the processes taken to identify the ideal methodology of detecting a human body while removing the background. Our first objective is to develop software capabilities while leveraging existing tools, such as the Kinect SDK and available libraries for various programming languages, to scan a body and remove background artifacts. The figures below were taken by our lead biomedical software developer at the USAISR, Craig Fenrich, and with permission are used to describe our results for this quarterly report to show the proof of concept.

i. 3D Object Scanning

3D Object scanning is necessary to capture a patient and register burn wound images to specific body regions for application on a standard burn wound diagram. We initially planned to use the Kinect Infrared camera for this task and initial work was performed with this system. Our first approach was to scan a human body as a 3D image because the Microsoft Kinect SDK provides a 3D depth map that can be translated into a 3D image. We believed that this method would be the most accurate in assuring that the person scanned along with the burns would have the least amount of digital manipulation to accurately depict a burn on a patient body as opposed to a 2D representation (A 3D body provides more accurate a body surface area estimation than a 2D representation).

When we initially processed the 3D mapping, the program required the subject to be relatively stationary. For a full body scan, the sensor (Kinect) must be moved slowly and in a linear fashion otherwise it would distort the 3D image. Additionally, the results showed that the overlay of the 3D image with texturizing in relation to IR distance produced an image that included all objects within the clipping plane (seen in Figure 1).

To develop utilizing the Kinect SDK along with the integrated development environment, Visual Studio 2017, we had to code in C# for the depth map. However, to incorporate both depth imaging and 3D image development, a 3D graphics library such as OpenGL for C# was required. We looked for the 3D Open Graphics Library (Open GL) for C# but the version available is not currently supported; however we did find a Java library for the Kinect system (J4K) that uses OpenGL for 3D and uses a port of the Kinect SDK to Java.

We used a Java based library called J4K library along with OpenGL and incorporated 3D development, but the processing speed was extremely slow. Potentially, multiple Kinect sensors could be used to increase the processing speed to simultaneously scan a subject at the same time but is not applicable for this project.
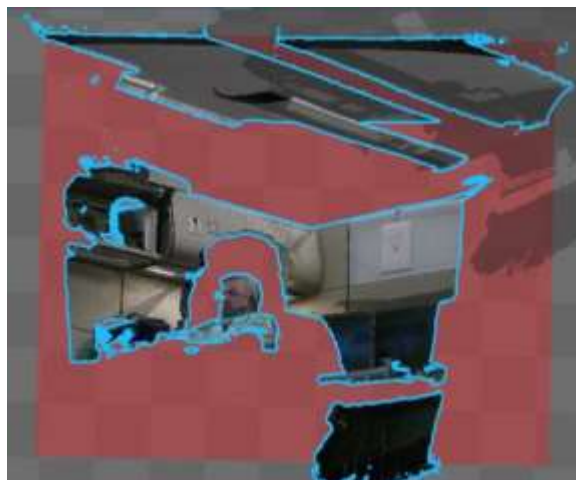

Figure 1. The 3D image scan while the subject is sitting still. The texture and depth map shows incomplete depiction of the subject and the surrounding environment.

Based on our results, we then proceeded with 2D development and continued with the J4K Java libraries. We created a depth map along with edge map detection using IR. The edge image that was created mapped the picture of the body using the body frame from the Kinect SDK or the distance mapping. Although this method worked, the resolution of the depth image from the IR and visual image did not match correctly using the current Java capabilities. Therefore, we implemented the original Kinect SDK with C# methods which had the capabilities for correlating the IR depth map (512X424) bitmap to the visual picture (1920X1080) bitmap. After testing, the decision was made to implement C# instead of Java.

Below in Figure 2, on the right side of the figure in red, the IR depth map image displays the infrared depth map. Based on the shading, the color gradient displays the distance from closest (brighter) to further (darker). Depth and visual overlay pictures are shown in Figure 3 and 4. The Kinect also has an edge detection function, shown in Figure 5.

Figure 2. Photograph with body frame skeletal image (left upper); Body frame skeletal image (left bottom); Infrared Image (right).
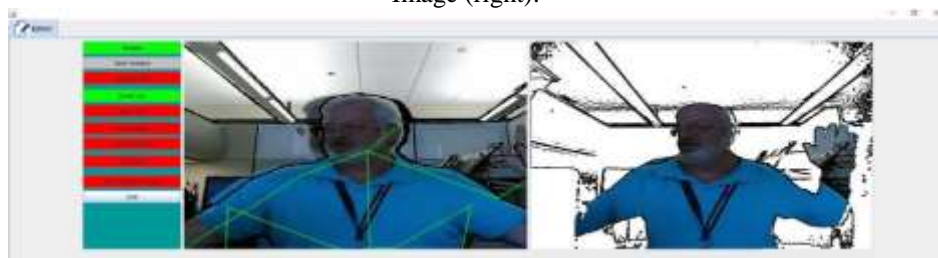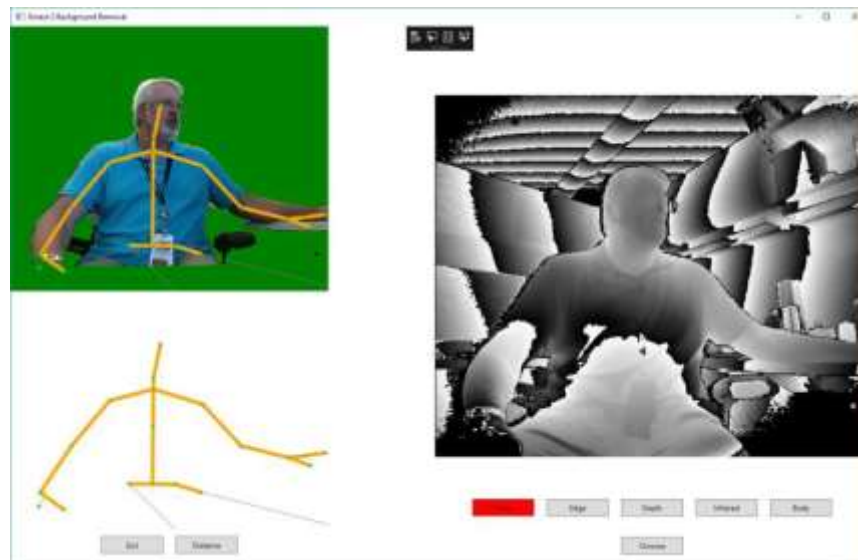
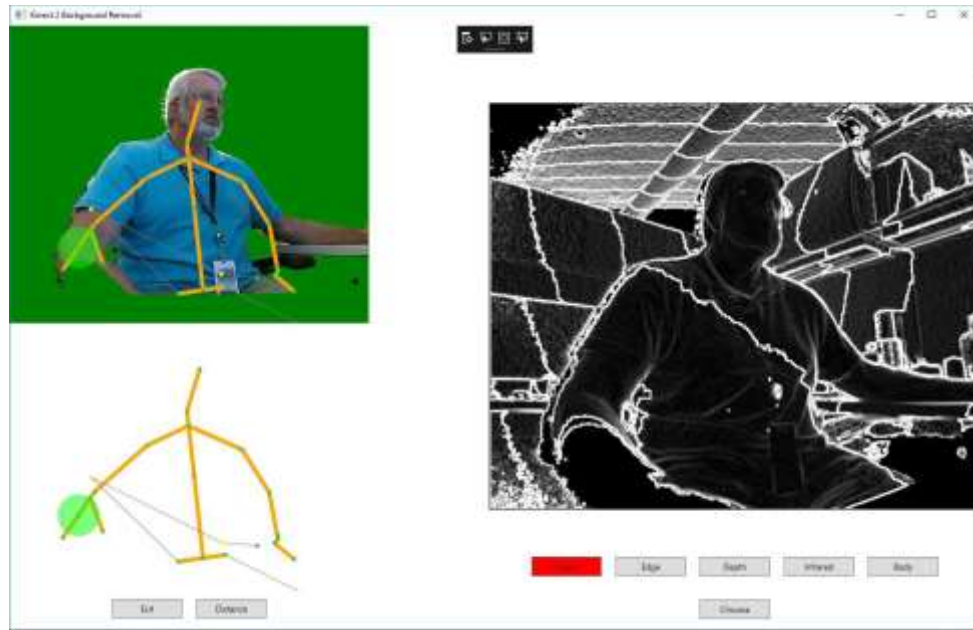Figure 3 Depth image with visual overlay

Figure 4 Depth image (right)

Figure 5 Edge detection image (right)

ii. Body Mapping

We have tested 3 different methods for mapping the body apart from the background or any other artifact. Based on our previous results, we have eliminated the 3D body mapping because it produced more errors in body recognition and was considerably slower in processing. The three methods we have identified and are currently testing are 1) Body frame detection; 2) Distance reference; and 3) Chroma key technique.

1. Body Frame Skeletal Detection from Kinect SDK

The Kinect system incorporates a machine learning algorithm for body tracking. It is able to track up to 25 joints of the body. Therefore, the body tracking allows the program to discern not only a body frame from the environment but also the movable limbs. This has been useful for detecting specific movements. Based on our evaluation, the sensitivity and accuracy of the body tracking is not as stable and can jitter when the program is evaluating the body joints in real time. Below in Figure **6**, the joint-skeletal frame is tracked in real time.
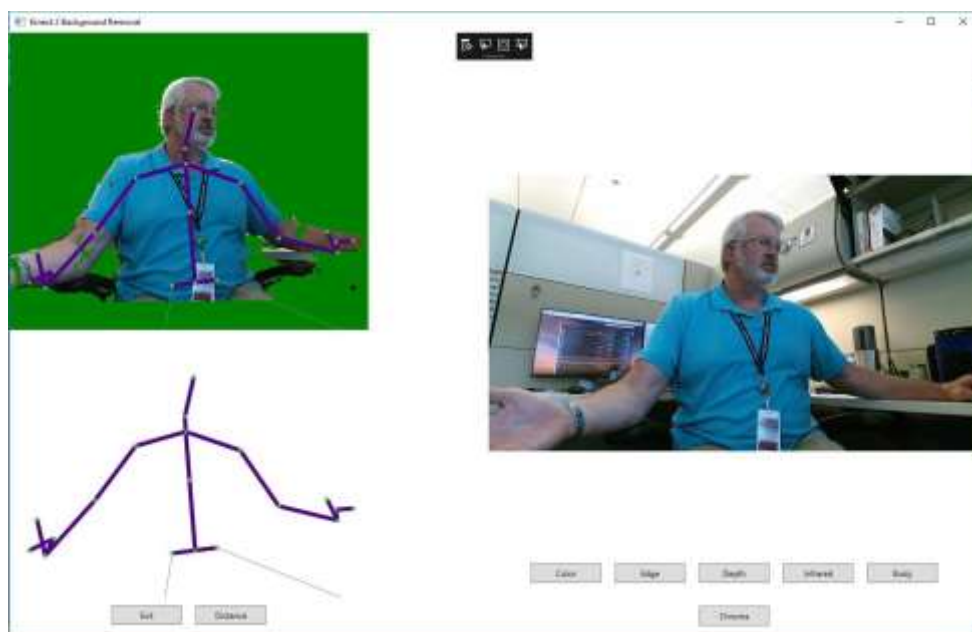
Figure 6 Body Tracking Image

2. Distance Reference from Kinect

The distance reference method works by telling the program the distance of where the subject is compared to the rest of the background. Example, the subject must be within 8 meters of the camera and everything beyond it is considered background. Based on our initial results, we found that this method is less accurate because it will also incorporate any other object within that distance as well. Example seen in Figure 7, the arms of the chair are in the same plane, therefore are included in the distance reference picture.
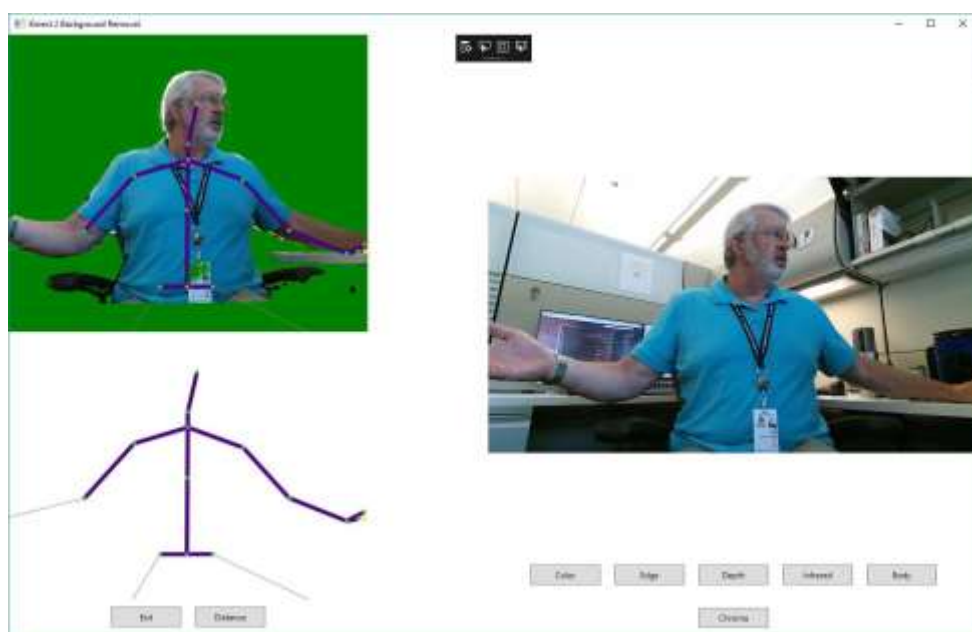

Figure 7 Distance image

3. Chroma Key

The third method utilizes a Chroma (or color) key that uses a color as a reference point for the background. This method is also known as the "green screen" that is used in video when adding or removing an artificial background. We used an open source Chroma Key algorithm and modified it to work with the camera on the Kinect. We took photos using the Kinect camera and ran the picture through the Chroma Key algorithm.

Using Chroma key, we can utilize any dark contrast color. Here in Figure 8, we used blue sheets and towels that are commonly used in the Burn Intensive Care Unit (BICU) as the Chroma key. The program detected the color and has colored it in pink. Because the shirt is also blue, it was also added to the Chroma key.

Figure 8 Body Tracking and Chroma key Image

Using the Chroma key methodology our next step was to test the MS Kinect with a mannequin lying on the floor to simulate a burned combat casualty. We discovered that the body frame (skeletal) detection from Kinect did not perform correctly (or at all) when the Kinect was pointed downward. Upon further investigation we found that it was the accelerometer built into the Kinect system that disables its function unless pointed forward at a person standing or sitting. Since this was not acceptable for what we were trying to accomplish we decided to look at using a Chroma Key methodology for body frame detection.

Believing that the Chroma key methodology had some potential, we focused our efforts on refining our Chroma key algorithm. This algorithm utilizes a blue background and replaces the blue background with the human body diagram from the Tactical Combat Casualty Care (TC3) card. (See figure 9.) We placed the mannequin on blue sheets on the floor and took pictures using the Kinect to test this methodology. This appeared to be working as shown in the photos below.

Figure .10 Picture of mannequin lying on floor using Chroma Key

Since the Chroma key methodology would only utilize the RGB camera of the Kinect system and not take advantage of the IR camera of the Kinect which produces the depth map, and would also require a separate computer connected to the Kinect (not feasible for the field environment) we developed an Android application that would allow the Chroma key algorithm to utilize the camera on a smart phone. This is shown below in Figure 10.

We also searched for an Open Source SDK that could do body silhouette detection as does the Kinect but would work when the camera was pointing in any direction and found an SDK called OpenCV. The proof of concept of this SDK worked, but the OpenCV library does not do actual body silhouette detection like the Kinect is capable of doing; it does more of human detection.

iii. Image Stitching

Image stitching is necessary to connect multiple pictures of the same patient into a single registered image. If multiple photos of burn wounds are take on a single patient, these images must be stitched to a common frame of reference, the burn wound image diagram. We tested two open source computer vision libraries, one was OpenCV and the other was BoofCV to support image stitching.

Figure 9 Picture taken with Chroma key application and an Android smart phone

We first took photos of a mannequin in the BICU with the hope of being able to stitch together the images of all of the body parts, we also used a blue background to also test the ChromaKey which is also part of the OpenCV library. Unfortunately, the mannequin has very few distinctive points for the stitching algorithm in either library to be able to stitch the images together so a fiduciary marker in the form of a QRF code was manually inserted on a photo of the trunk and the left arm. We ran the algorithm again using both BoofCV and OpenCV. OpenCV did slightly better at stitching the photos together.

Figure 11 Mannequin arm with QRF marker, Image 12 Mannequin trunk with
marker, Image 13 images stitched together using OpenCV.

We took numerous photos of a human volunteer using four sheets with the QRF marker placed at the left shoulder, right shoulder, left hip, and right hip. However, based on this brief experiment, we determined that a unique marker is necessary for each location. The next round will be done with four unique markers.
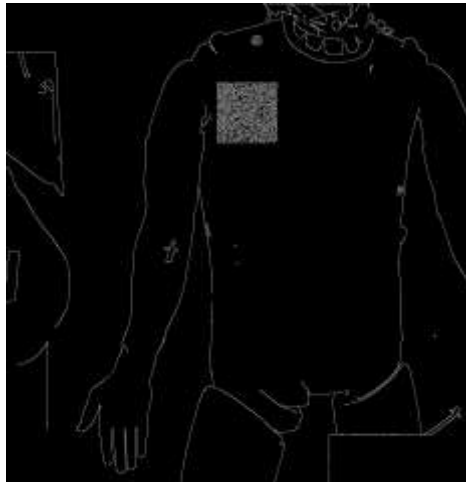

Figure 12 Body Silhouette using Canny Edge Detection

3. Animal Burn Wound Image Capture

The following are active animal protocols during which we may obtain images. No amendment or new protocol is necessary for passive image capture during these ongoing animal protocols.

- Protocol #A-16-021-TP: Evaluation of Tissue Engineered Therapies in a Porcine (Sus scrofa) Skin Injury Model - A Type Protocol Animal Protocol PI: Randolph Stone II, PhD
- Protocol #A1730 : Optimization of Debridement Depth that Results in Complete Graft Take for Porcine Burn Wounds Animal Protocol PI: Randolph Stone II, PhD
  - Protocol A1730: First images were taken of Porcine experiment #9901 on Sept 7, 2017. Porcine model had approximately 2X2" (x12) squares not including tattoo area with each square with varying burning times to capitulate varying burn severity (0 seconds - 15 seconds). Histology report of actual burn depth has not been recorded at this time. We took images of approximately 2 hours post burn using the FLIR ONE pro (Android device) camera.
  - Protocol A1730: We took images of a pre-burn porcine model on Sept 8, 2017. Porcine had 12 tattooed squares but with no burns; we wanted to test out the capabilities of the FLIR ONE camera

and develop a workflow for taking visual and IR images as well as documentation and distance from skin to camera. We also realized we needed a reliable thermometer and humidity device as additional data points.
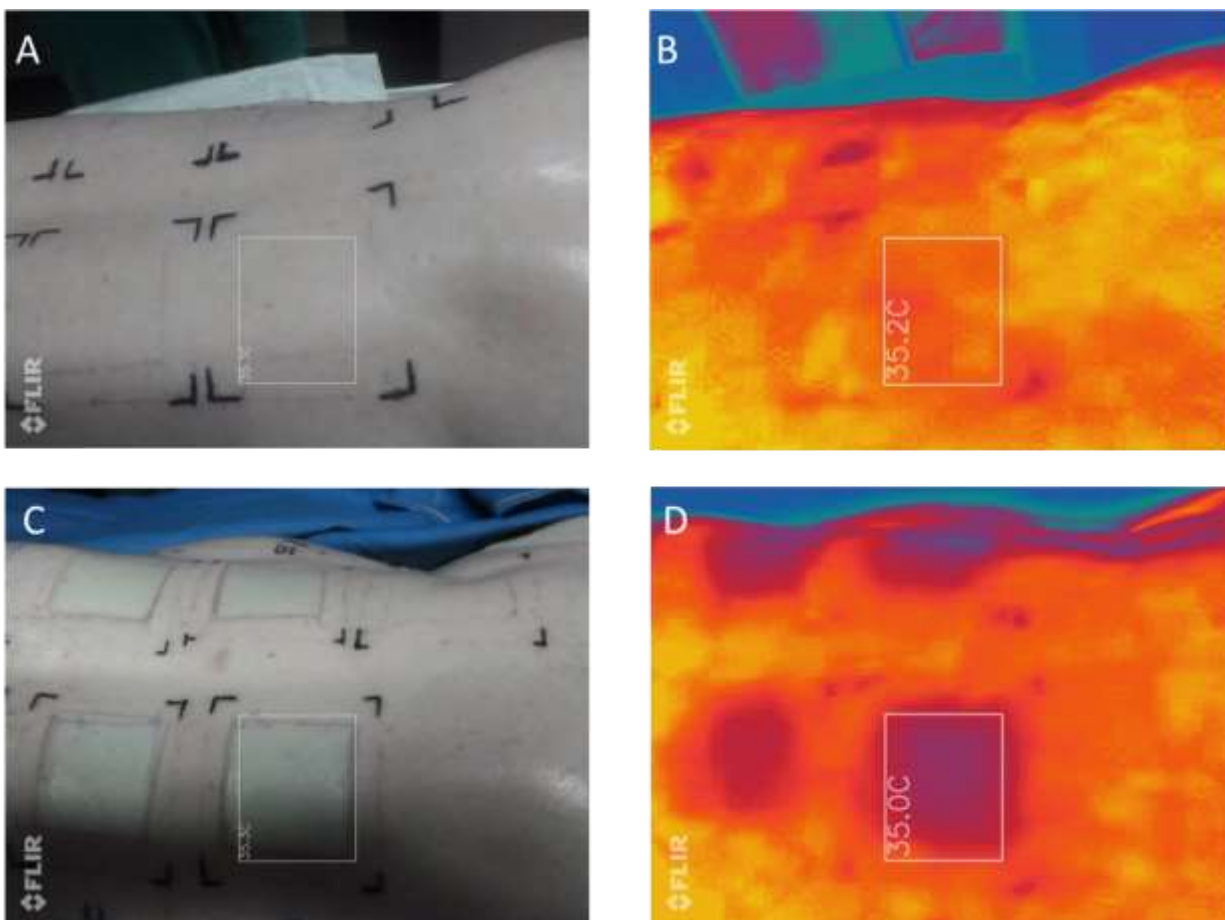
4. Deliverables Status

The deliverables for the BURNMAN project to date are:

1. Multispectral Camera Delivery: Nov 24, 2017
2. Animal Use Protocol amendment approval: NA. No animal protocol needed for passive image capture only per USAISR IACUC.

Pending deliverables include:

1. Human Use Protocol: Draft protocol written.

The following are planned for the next reporting period:

a. Installation of multispectral camera system in the Animal ICU for burn wound image capture
b. Animal burn wound data for ML model development
c. Enhanced burn wound diagram

The figure below shows the updated project research schedule in Gantt chart format. It has been adjusted from the original submission to account for the development delays associated with ARA's contract award.

Task Number	Task Description	2016	2017	2018	2019
		Jun Jul Aug Sep Oct Nov Dec	Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec	Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec	Jan Feb Mar Apr May Jun Jul Aug Sep
Objective 2	Create Dataset				
Task 1	Deliver Multispectral Camera				
	The USAISR submits and obtains IRB and IACUC approvals				
	Capture Manikin images for processing				
	Capture animal burn wound images				
	Capture human burn wound images				
Task 2	Create enhanced burn wound diagrams				
Task 3	Pre-process multi-spectral burn wound images				
Objective 3	Compare results of the burn wound mapping and total body surface area (%TBSA) estimates				
Task 1	Receive de-identified enhanced data set from USAISR.				
Task 2	Use enhanced burn wound diagrams and their proprietary software to trace wounds to estimate percentage (%) of TBSA				
Task 3	Send enhanced burn wound diagrams estimated percentage (%) of TBSA to USAISR for clinical experts review				
Task 4	Receive de-identified enhanced data sets with USAISR clinical expert annotations, split into training and evaluation sets				
Objective 4	Create a Machine Learning (ML) software model to create a predictive model of burn				
Task 1	Create ML algorithms to automatically estimate burn wound depth and per cent TBSA burned.				
Task 2	Demonstrate the ML algorithm				
Task 3	Compare ML output to clinical expert assessment of burn wounds				
Objective 5	Produce the reference design for a mobile camera-computer platform				

5. Administrative

Applied Research Associates, Inc. (ARA) has been under Contract W81XWH-12-C-0126 to the U.S. Army Medical Research & Material Command's (USAMRMC) Telemedicine & Advanced Technology Research Center (TATRC) for two months. We have ordered the spectral camera with anticipated delivery of Nov 24.

Meetings − The team participates in regularly scheduled team meetings and occasional WebEx conferences to further review and discuss the development of BURNMAN.

- BURNMAN bi-weekly project technical progress meetings (Thursday)
- BURNMAN bi-weekly project management meetings (Friday)

6. Equipment and Supplies

We have ordered the Multispectral camera for the project, a Kinect camera and Dell Precision 7510 laptop for managing the cameras.

The following supplies have been ordered for the project:

- Extendable camera boom
- Hardware for mounting the camera boom
- 2-camera mounting platform
- Intel RealSense Camera
- Microsoft Kinect Camera

7. Reportable Outcomes

There are no reportable outcomes to date for this project.

8. Conclusions

The BURNMAN project has only just started with the award of the contract to ARA and OSU. The first year was spent primarily in coordination activities and some initial technology review to identify the best technologies for image data acquisition.

We have made reasonable progress in technology review, identifying a number of candidate cameras and down-selecting to the best for use in the project. Now that the technology has been identified and ordered, data acquisition will begin in earnest during the next reporting period.

9. References

NONE

10. Appendices

NONE